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ON THE FUNCTIONS OF THE CHANGEOVER DELAY

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The function of changeover delays in producing matching was examined with pigeons responding on concurrent variable-interval variable-interval schedules. In Experiment 1, no changeover delay was compared to two different types of changeover delay. One type, designated generically as response-response but in the present example as peck-peck, was timed from the first response on the switched-to key; the other, designated generically as pause-response but in the present example as pause-peck, was timed from the last response on the switched-from key. High changeover rates occurred with no changeover delay. Peck-peck and pause-peck changeover delays produced low and intermediate changeover rates, respectively. In Experiment 2, pause-peck and peck-peck changeover delays were compared across a range of relative reinforcement rates. Similar matching relations developed despite differences in the changeover rates and local response patterns as a function of the type of changeover delay. In Experiment 3, both types of changeover delay yielded similar changeover rates when their obtained durations were equal via yoking. The results suggest that changeover delays function to separate responses on one key from reinforcers on the other or to delay reinforcement for changing over. In addition, the distribution of responding during and after the changeover delay may vary considerably without affecting matching.

Key words: concurrent schedules, changeover delay, delay of reinforcement, matching, key peck, pigeons

The matching relation between response rates and reinforcement rates arranged by two concurrently available variable-interval (VI) schedules (Herrnstein, 1961; see Catania, 1966, de Villiers, 1977, and Davison & McCarthy, 1988, for reviews) is obtained most reliably when a changeover delay (COD) is in effect. Such a changeover delay "allows a response to be reinforced only if a certain interval of time has passed since the last changeover from the other response" (Catania, 1966, p. 216).

At least two functions of the COD have been proffered. The most frequent is that it prevents the adventitious reinforcement of changing over, resulting in longer periods of responding at the alternatives and thus greater control by relative reinforcement rates (e.g., Baum, 1979; Catania, 1966; Catania & Cutts, 1963; Herrnstein, 1961). It has been suggested that matching occurs as a result of this latter control. A second suggestion is that the COD produces rates of responding during and after the COD that combine to result in matching.

The function of the COD in temporally separating reinforcement and responding on the two alternatives has been assessed by comparing conditions in which no COD is present to conditions in which a COD is in effect (e.g., Herrnstein, 1961; Pliskoff, 1971; Shull & Pliskoff, 1967; Temple, Scown, & Foster, 1995). Rates of changing between the alternatives decrease with increases in COD duration (Pliskoff, 1971; Shull & Pliskoff, 1967; Temple et al., 1995). The matching relation is more reliably obtained with longer than shorter CODs; however, the quantitative index of the correspondence between relative response and reinforcement rates reaches asymptote at a value near that reflecting matching. Further increases in the COD duration do not affect matching (Temple et al., 1995). In these analyses, however, changes in the degree of separation of the alternatives often are confounded with changes in COD and post-COD response rates (e.g., Pliskoff, 1971).

Concerning the role of the COD in controlling local rates that in turn determine matching, Silberberg and Fantino (1970) re-

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ported higher response rates during than after the COD and presented functions relating relative response rates to relative overall reinforcement rates for COD and post-COD responding separately. Relative responding during the COD tended to severely undermatch relative overall reinforcement rates, and relative responding after the COD tended to overmatch relative overall reinforcement rates (see also Temple et al., 1995). When COD and post-COD response rates were combined, matching was obtained. Silberberg and Fantino (1970) concluded that matching depends on the combination of high COD response rates and lower post-COD response rates. However, the role of the COD in producing COD and post-COD response rates as compared to its role in separating the alternatives remains unclear.

Changeover delays have been arranged in two ways. One way (referred to generically as a response-response or, in the present case, a peck-peck COD) is to start the COD with the first response on the changed-to alternative. This is the COD most common in concurrent-schedule research. The other way (referred to generically as a pause-response or, in the present case, a pause-peck COD) is to begin timing the COD with each response on the changed-from schedule, allowing the first response on the changed-to schedule to be reinforced (cf. Catania, 1966; Findley, 1958). A parallel situation exists in changeover-operandum (CO-operandum) procedures. In the CO-operandum procedure, the COD typically is timed from a response on the CO operandum (e.g., Stubbs & Pliskoff, 1969), resulting in a COD similar to a pause-response COD in that the response that initiates the COD is not on the changed-to alternative and the first response on the changed-to alternative may be reinforced. A COD similar to the peck-peck COD also has been used in CO-operandum procedures in which the COD is timed from the first response on the main key after a CO-operandum response (Guilkey, Shull, & Brownstein, 1975; Pliskoff, 1971).

Although direct comparisons of the two COD arrangements have not been made, comparisons across different experiments suggest that the two may yield differences in performance. Iversen (1981) compared concurrent VI VI responding of rats under conditions in which either no COD was in effect for either lever or a pause-response or response-response COD was in effect for changeovers to one alternative. Compared to conditions in which the COD was absent, response rates increased on the alternative for which either type of COD was scheduled. The response-response COD increased response rates more than a pause-response COD relative to the no-COD condition. Iversen's (1981) data suggest that response-response and pause-response CODs may produce response-rate differences. The effects of these differences on matching are unclear, however, because pause-response or response-response CODs were programmed for only one alternative at a single relative reinforcement rate. Using a CO-operandum procedure and CODs in effect for both schedules, Guilkey et al. (1975) also showed that response rates during the COD were higher when the COD was timed from the first response on the main key after a CO response (similar to a response-response COD) than when timed from a CO response (similar to a pause-response COD). However, the effects of the two types of COD were comparable only across experiments and only at one relative reinforcement rate.

The experiments described in the preceding paragraph suggest that different CODs might produce differences in local response rates. Because both types of COD maintain at least nominally similar temporal separation between alternatives, a comparison of the two COD arrangements could prove to be valuable in assessing the effects of different local response rates in yielding matching, as suggested by Silberberg and Fantino (1970). The first experiment therefore was a preliminary one in which we directly compared the effects of the two types of COD described above with the absence of a COD. The results of that experiment led in turn to a more detailed analysis in Experiment 2 of the role of the COD in determining local response rates in concurrent schedules and the relation of those data to matching. The final experiment further clarified the role of temporal variables that were operative in the second experiment.

EXPERIMENT 1

The effects of a pause-peck COD, a peck-peck COD, and no COD on response rates and changeover rates were compared on two-key concurrent VI 3-min VI 3-min schedules.

METHOD

Subjects

Three retired breeder male White Carneau pigeons were maintained at 80% of free-feeding weights. Each had a history of responding on several schedules of reinforcement.

Apparatus

A sound-attenuating operant conditioning chamber with internal dimensions of 38 cm by 31 cm by 31 cm was used. Two response keys (2 cm diameter) were located 5 cm from either side wall of the chamber, 21 cm apart (center to center), and 25 cm from the floor. Each key required a force of approximately 0.15 N to operate and was transilluminated white at all times except during reinforcement, which consisted of 3-s presentations of mixed grain from a grain hopper. The hopper was accessible, when raised, through an aperture (6 cm by 6 cm) located on the midline of the work panel with its center 11.5 cm from the floor. The aperture was illuminated by a 28-VDC clear bulb when the hopper was operated. A ventilation fan attached to the chamber also masked extraneous noise. Contingencies were programmed and data were recorded on electromechanical equipment and two Gerbrands Model C3 cumulative recorders located in an adjacent room.

Procedure

Each pigeon was initially trained to key peck on VI schedules with increasing mean interreinforcer intervals on each key separately until it responded reliably on a VI 0.5-min schedule. Subsequently, concurrent VI 1-min VI 1-min schedules were arranged with a 3-s peck-peck COD. When responding reliably occurred, concurrent VI 3-min VI 3-min schedules were effected and remained in effect throughout the experiment. All VI schedules were composed of 20 intervals and were constructed according to the constant probability distribution described by Fleshler and Hoffman (1962).

The effects of a 3-s peck-peck COD, a 3-s pause-peck COD, and no COD then were compared. The peck-peck COD was programmed such that the first response on the changed-to key initiated the COD, after which a reinforcer could be delivered if available. The pause-peck COD was timed from the last peck on the changed-from key such that the first peck on the changed-to key could be reinforced if it was temporally separated from the last changed-from peck by at least 3 s. When no COD was in effect, a reinforcer could be delivered immediately following a peck on either key independently of pecking on the other key. Table 1 shows the order of conditions and number of sessions in each. Each subject was initially exposed to the 3-s peck-peck condition. Subsequently, 2 pigeons were exposed to the pause-peck COD condition, followed by the no-COD condition. The 3rd pigeon was exposed to the no-COD condition subsequent to the initial peck-peck condition, followed by the pause-peck condition. Each pigeon was returned to the peck-peck COD condition after exposure to both pause-peck and no COD conditions.

Table 1

Sequence of conditions in Experiment 1.

Pigeon	COD in effect	Number of sessions
4891	Peck-peck	19
	Pause-peck	36
	Peck-peck	48
	No COD	35
	Peck-peck	60
442	Peck-peck	19
	Pause-peck	38
	Peck-peck	36
	No COD	37
	Peck-peck	19
4810	Peck-peck	23
	No COD	15
	Peck-peck	47
	Pause-peck	42
	Peck-peck	36

Two stability criteria were met in each condition. Response-rate stability required that over a 6-day period, the first 3-day and second 3-day means did not differ by more than 5% from the 6-day mean. Stability in the number of changeovers per session (with the addition of a constant of 100) required that over a 6-day period, the first 3-day and second 3-day means not differ by more than 10% from the 6-day mean. Each condition was in effect for a minimum of 13 sessions. Sessions were conducted 5 days per week at approximately

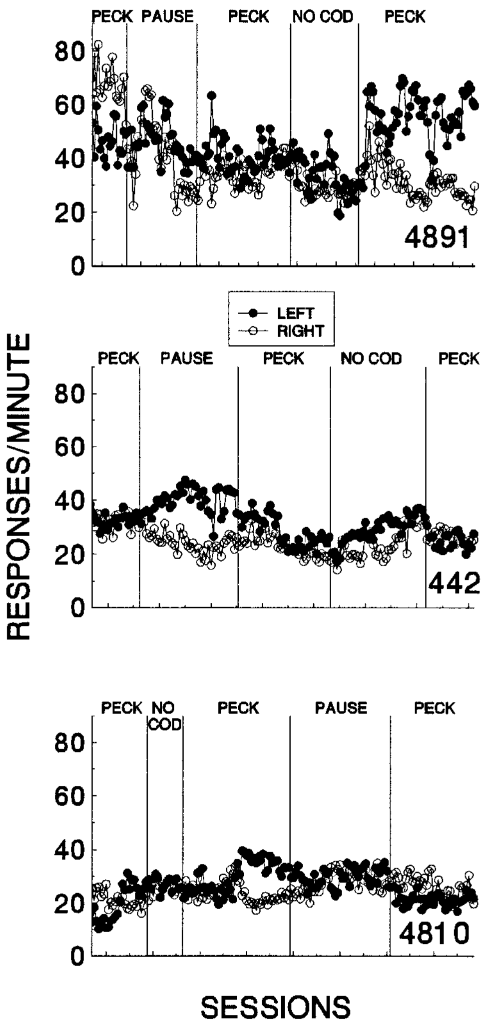

Fig. 1. Absolute response rates for each subject in the peck-peck, pause-peck, and no-COD conditions. Open circles represent the right key, and filled circles represent the left key.

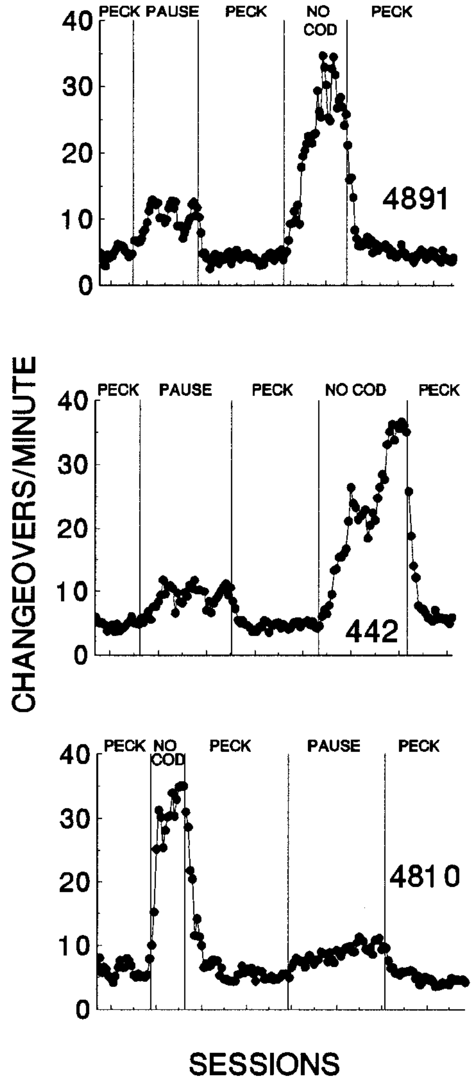

Fig. 2. Total changeovers per minute (left and right changeovers divided by total session time) for peck-peck, pause-peck, and no-COD conditions.

the same time each day and ended after 60 min.

Results

Figure 1 shows that for each pigeon there were no systematic differences in response rates across the peck-peck, pause-peck, and no-COD conditions. (In this and all subsequent figures, pause and peck refer to pause-peck and peck-peck CODs, respectively.) Figure 2 shows that changeover rates (total changeovers divided by total session time) were higher in the pause-peck conditions than in the peck-peck conditions. Changeover rate in the no-COD condition was higher than in either the pause-peck or peck-peck conditions. Figure 3 shows sample cumulative records from the left key for Pigeon 442 in all conditions of the experiment. Left-key and right-key cumulative recorders ran continuously throughout the session; therefore, periods of responding at one alternative are accompanied by periods of no responding at the other. The peck-peck COD produced long periods of responding at the alternatives (as seen by the large step-wise grain), and the

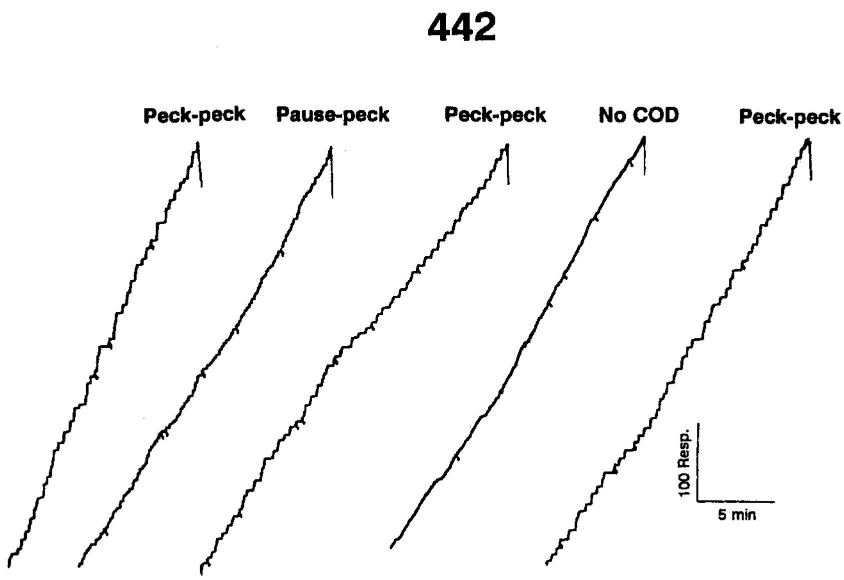

Fig. 3. Sample cumulative records for Pigeon 442 from stable performance in the peck-peck, pause-peck, and no-COD conditions. Pen deflections represent reinforcer deliveries, and records reset after 550 responses. Records are presented for the left key only.

pause-peck COD produced shorter periods of responding at the alternatives (as seen by the smaller step-wise grain). When no COD was in effect, nearly strict alternation between the keys occurred (as seen by the absence of grain in the record).

DISCUSSION

Systematic differences in response rates were not obtained in the pause-peck, peck-peck, and no-COD conditions. These data are consistent with other data showing no changes in relative response rates with equal VIs when comparing no COD to peck-peck CODs of increasing duration (Stubbs & Pliskoff, 1969). However, these data are not consistent with Iversen's (1981) findings of increased absolute and relative response rates with a response-response COD compared to a pause-response COD and no COD. Perhaps the increases in absolute and relative response rates noted by Iversen resulted from the addition of a pause-peck or peck-peck COD to only one of the concurrent schedules. Effects similar to those found by Iversen have been noted with relative response rates when CODs of unequal durations were effected in concurrent schedules (Pliskoff, 1971).

Despite similar absolute and relative response rates across peck-peck, pause-peck, and no-COD conditions, the rates of changing over differed. During the peck-peck and no-COD conditions, changing between the alternatives was, respectively, lowest and highest. This effect is similar to the decreasing changeover rates that occur with increases in COD duration (Pliskoff, 1971; Shull & Pliskoff, 1967; Stubbs & Pliskoff, 1969; Temple et al., 1995). The pause-peck COD produced rates of changing over that were intermediate to those produced by peck-peck and no-COD conditions.

The differences in rates of changing over that were obtained with pause-peck and peck-peck CODs may result from the extent to which each separates responses on one key from reinforcers on the other. The time between a response on one key and a reinforcer delivery on the other (referred to hereafter as the obtained COD) could have differed for the two types of COD. The peck-peck COD specifies a minimum amount of time that must elapse between a response on the changed-to key and the possibility of a reinforcer on that key, whereas the pause-peck COD specifies a minimum amount of time between a response on the changed-from key and the possibility of a reinforcer delivery on the other. As a result, the peck-peck COD could produce longer obtained CODs because the amount of time required to switch between the alternatives is not included in the specified duration. This possibility was examined in the next experiment, when the range of reinforcement rates on either operandum was expanded.

EXPERIMENT 2

In this experiment, the effects of pause-peck and peck-peck CODs were investigated across a range of relative reinforcement rates to further examine the role of the COD in yielding matching in concurrent schedules. Responding during and after the COD was compared in terms of rate and in terms of the generalized matching relations that described the data produced by each COD. Post-COD and COD matching functions were compared to matching functions describing all responding at the alternatives (cf. Silberberg & Fantino, 1970; Temple et al., 1995). Furthermore, obtained CODs were compared for pause-peck and peck-peck CODs.

METHOD

Subjects

The subjects were those used in Experiment 1, plus another subject that also had a history of responding on several schedules of reinforcement. Each pigeon was maintained at 80% of its free-feeding weight.

Apparatus

An operant conditioning chamber (not the chamber used in Experiment 1) with internal dimensions of 33 cm by 30 cm by 30 cm was used. Two response keys (2.8 cm diameter) were mounted 6 cm from either side wall of the chamber, 12 cm apart (center to center) and 25 cm from the floor. Each key required a force of approximately 0.15 N to operate and was transilluminated white at all times except during reinforcement, which consisted of 3-s presentations of mixed grain from a grain hopper. The hopper was accessible, when raised, through an aperture (4.5 cm by 6 cm) that was located on the midline of the work panel with its center 9.5 cm from the floor. The aperture was illuminated by a clear 28-VDC bulb when the hopper was operated. A ventilation fan and white noise masked extraneous noise. Contingencies were programmed on a Tandy 1000ex computer programmed using Med-PC® software (MED Associates, Inc. & Tatham, 1991). Two Gerbrands Model C3 cumulative recorders were used to record responses on each key.

Table 2

Sequence of conditions in Experiment 2.

Pigeon	COD in effect	VI (min) Left	VI (min) Right	Number of sessions
442	1 (2)	3	3	15 (15)
		1.8	9	15 (16)
		2.25	4.45	15 (15)
		9	1.8	15 (28)
4810	2 (1)	3	3	16 (15)
		1.8	9	15 (15)
		2.25	4.45	16 (15)
		9	1.8	15 (28)
4891	1 (2)	1.8	9	15 (16)
		3	3	15 (15)
		9	1.8	21 (37)
		2.25	4.45	15 (15)
2372	2 (1)	1.8	9	17 (15)
		3	3	16 (15)
		9	1.8	15 (15)
		2.25	4.45	17 (24)

Note. COD 1 = pause-peck, COD 2 = peck-peck. CODs and session numbers in parentheses correspond to conditions presented second.

Procedure

Each subject was exposed to four pairs of concurrent VI VI schedules, each with an average combined interreinforcement interval of 1.5 min. Each of the VI schedules was constructed in accord with the constant probability distribution described by Fleshler and Hoffman (1962). The schedules were concurrent VI 1.8 min VI 9 min, concurrent VI 2.25 min VI 4.5 min, concurrent VI 3 min VI 3 min, and concurrent VI 9 min VI 1.8 min. The first schedule listed in each pair was in effect on the left key, and the second was in effect on the right key. Each concurrent schedule included at different times a 3-s peck-peck or a 3-s pause-peck COD. Table 2 shows the order of conditions and number of sessions in each. Data for Pigeon 4891 under the concurrent VI 3-min VI 3-min pause-peck condition were redetermined because of an earlier strong response-key bias during the first exposure to this condition. Data for this condition are presented from the second determination only.

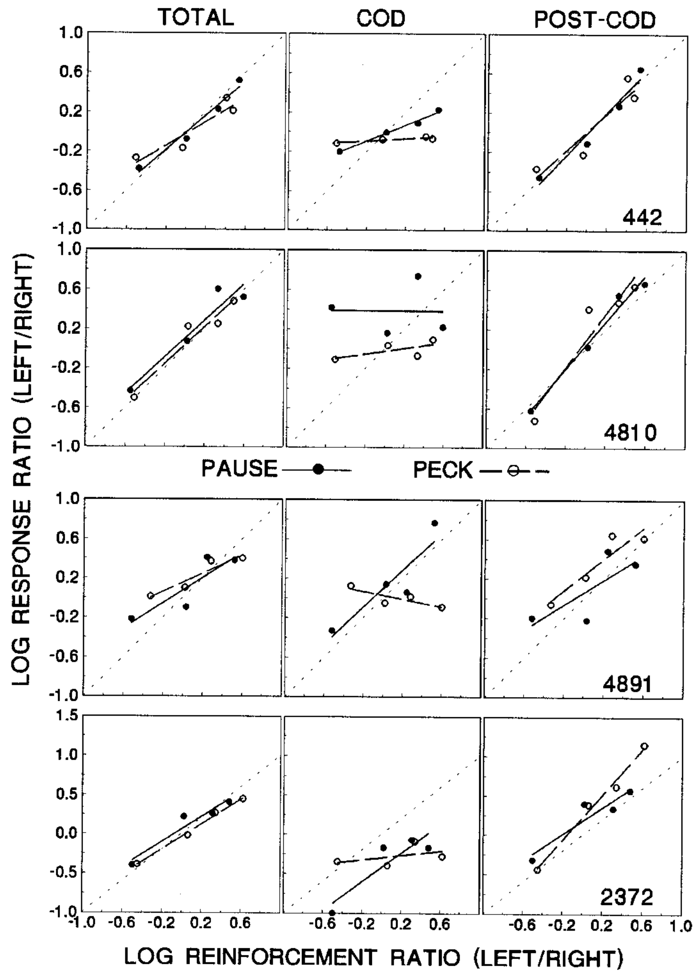

Fig. 4. Log response ratios for total responses (left panels), COD responses (center panels), and post-COD responses (right panels) for the left key as a function of log obtained reinforcement ratios for the left key. Fitted lines are least squares regression lines for pause-peck (dashed line and open circles) and peck-peck (solid lines and filled circles) conditions. Parameters of fitted lines are available in Table 3. The light dashed diagonal line indicates perfect matching.

Conditions were changed when stability in response proportions occurred. Stability was defined when five consecutive 5-day response proportion medians did not differ by more than ±.05 (see Davison & McCarthy, 1988). Sessions were conducted 5 days per week at approximately the same time each day and ended after 40 reinforcer deliveries.

Results

Figure 4 shows log obtained response ratios for total responses, COD responses, and post-COD responses as a function of total log obtained reinforcement ratios for both pause-peck and peck-peck COD conditions. Post-COD responses were those responses that occurred after a COD had elapsed and before a changeover to the other schedule, and COD responses were those responses that occurred while a COD was timing. Fitted lines represent Baum's (1974, 1979) matching equation based on response and reinforcer ratios:

$$\log(B_1/B_2) = a \log(r_1/r_2) + \log b, \quad (1)$$

where B_1 and B_2 are response rates for the two schedules and r_1 and r_2 are obtained reinforcement rates. The empirically derived parameters b and a represent the degree of bias and under- or overmatching, respectively,

Table 3

Parameters of Equation 1 as obtained from least squares regression lines fitted to the data.

Pigeon	Condition	a	log b	r^2
442	Pause	0.87	−.01	.97
	COD	0.40	−.01	.99
	Post	1.06	−.01	.96
	Peck	0.60	−.02	.86
	COD	0.06	−.08	.86
	Post	0.91	.01	.86
4810	Pause	0.93	.10	.92
	COD	−0.01	.39	.00
	Post	1.19	.04	.98
	Peck	0.93	.03	.93
	COD	0.14	.03	.46
	Post	1.35	.09	.91
4891	Pause	0.63	.07	.78
	COD	0.91	.09	.83
	Post	0.62	.15	.59
	Peck	0.46	.17	.90
	COD	−0.20	.03	.68
	Post	0.79	.27	.88
2372	Pause	0.80	.06	.93
	COD	0.91	−.42	.81
	Post	0.85	.18	.87
	Peck	0.80	−.04	.99
	COD	0.14	−.30	.23
	Post	1.44	.22	.99

Note. Pause and peck refer to parameters for regression lines fitted to total data (COD + post-COD) for the pause-peck and peck-peck CODs, respectively. COD refers to parameters for regression lines fitted to COD data only, and Post refers to lines fitted to post-COD data only.

of behavior to the ratio of reinforcement. Parameters of Equation 1 obtained by fitting least squares regression lines to means of the last 5 days of each condition are presented in Table 3. Absolute data used in constructing ratios are available in the Appendix.

In general, when total responses were considered, both types of COD produced undermatching. When only COD responses were considered, severe undermatching was obtained with the peck-peck COD. When the pause-peck COD was in effect, severe undermatching was obtained during the COD only with Pigeon 4810. When only post-COD responses were considered, four functions showed overmatching and four showed undermatching, with no consistent differences between pause-peck and peck-peck CODs. Despite differences in the degree of undermatching obtained during the COD, when COD and post-COD responses were combined no consistent differences in the matching relation were found.

Figure 5 shows changeovers per minute as a function of log obtained reinforcement ratios for pause-peck and peck-peck CODs. Changeover rates were consistently higher across reinforcement-rate ratios when the pause-peck COD was in effect. In the plots for individual subjects, changeover rates did not appear to vary systematically with changes in reinforcement ratios for either type of COD. However, in the plots of mean data, rates of changing over often appear to be lower with more extreme reinforcement ratios.

In Figure 6, response rates during and after the COD are shown for pause-peck and peck-peck CODs across the range of reinforcement ratios. Response rates during the COD were calculated by dividing the total number of responses that occurred during the COD on each key by the total amount of time spent in the COD for each key. To make calculations as similar as possible for pause-peck and peck-peck CODs, the response that started a peck-peck COD was not included as a COD response (note that this response was on the other key for the pause-peck COD). Response rates after the COD were calculated by dividing the total number of post-COD responses for each key by total post-COD time accumulated for that key. Response rates were consistently higher during the COD with the peck-peck COD than with the pause-peck COD. Also, the peck-peck COD resulted in higher COD than post-COD response rates, whereas the opposite was true for the pause-peck COD. Neither COD produced consistent changes in COD and post-COD response rates as a function of programmed reinforcement ratio.

Figure 7 shows response rates for each key in 1-s bins for the first 10 s after the first response on the changed-to schedule. This analysis is presented for pause-peck and peck-peck CODs for each relative reinforcement-rate condition. The number of responses in each bin (including the first response on the changed-to key) was divided by the total amount of time spent in the bin. The amount of time spent in a bin was calculated by multiplying the bin size (1 s) by the number of occasions on which the bin was entered (cf. Menlove, 1975). For both pause-peck and peck-peck CODs, response rates were high in the first second after a response on the changed-to schedule and decreased as a func-

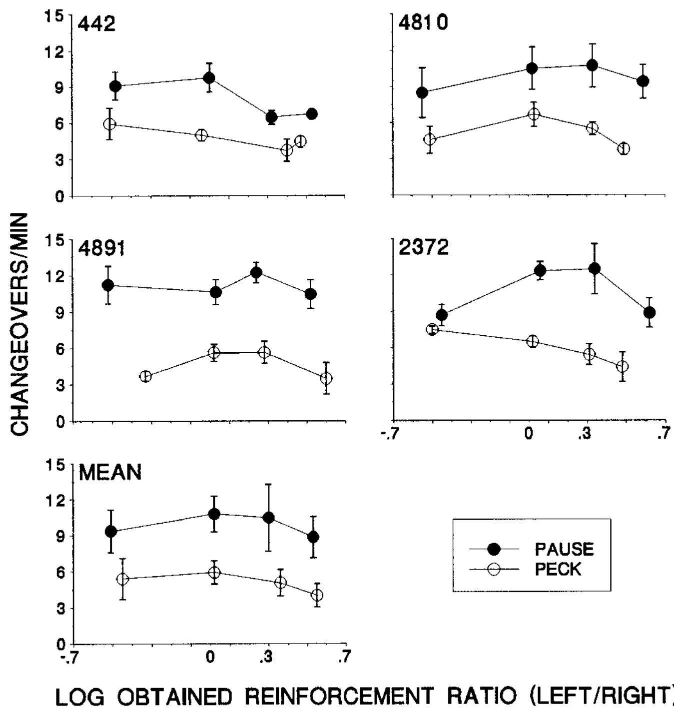

Fig. 5. Changeovers per minute for pause-peck and peck-peck conditions as a function of log obtained reinforcement ratios for the left key. Changeovers per minute was calculated by dividing total changeovers by session time (less reinforcer-access time). Data points represent means of the last five sessions of each condition, and vertical bars represent ±1 *SD*.

tion of time after a changeover. However, response rates in the pause-peck conditions tended to decrease more rapidly with the passage of time than those in the peck-peck conditions. The pattern of responding across the first 10 s after a changeover did not differ systematically with changes in relative reinforcement rate in the pause-peck or peck-peck COD conditions.

Figure 8 shows the proportion of reinforcers delivered immediately after a COD had lapsed (i.e., reinforcers delivered following the first response after the COD lapsed). Between 20% and 50% of all reinforcers occurred immediately following a COD. In general, more reinforcers occurred following a COD on the leaner schedule, and no consistent differences were observed between pause-peck and peck-peck CODs.

Figure 9 shows mean obtained COD durations for both types of COD. For this analysis, the COD was broken into two intervals. The first interval was defined by the amount of time between the last response on Schedule A and the first response on Schedule B ($A \rightarrow B$ in Figure 9). The second interval was defined by the amount of time between the first response on B and the delivery of a reinforcer on B ($B \rightarrow S^R$ in Figure 9). Then a third interval was defined as the sum of the first two intervals and represents the amount of time between the last response on A and the delivery of the next reinforcer on B. This analysis was performed only for CODs that terminated in the delivery of a reinforcer (the proportion of which for each condition may be obtained from Figure 8). Total obtained CODs were longer with the peck-peck COD than with the pause-peck COD. Much of this difference occurred as a result of the forced longer intervals between the first response on Schedule B and the delivery of a reinforcer on B for the peck-peck COD (i.e., $B \rightarrow S^R$ intervals). The intervals between the last response on A and the first response on B varied considerably across subjects and conditions (i.e., $A \rightarrow B$ intervals). In addition, total COD duration was more variable with

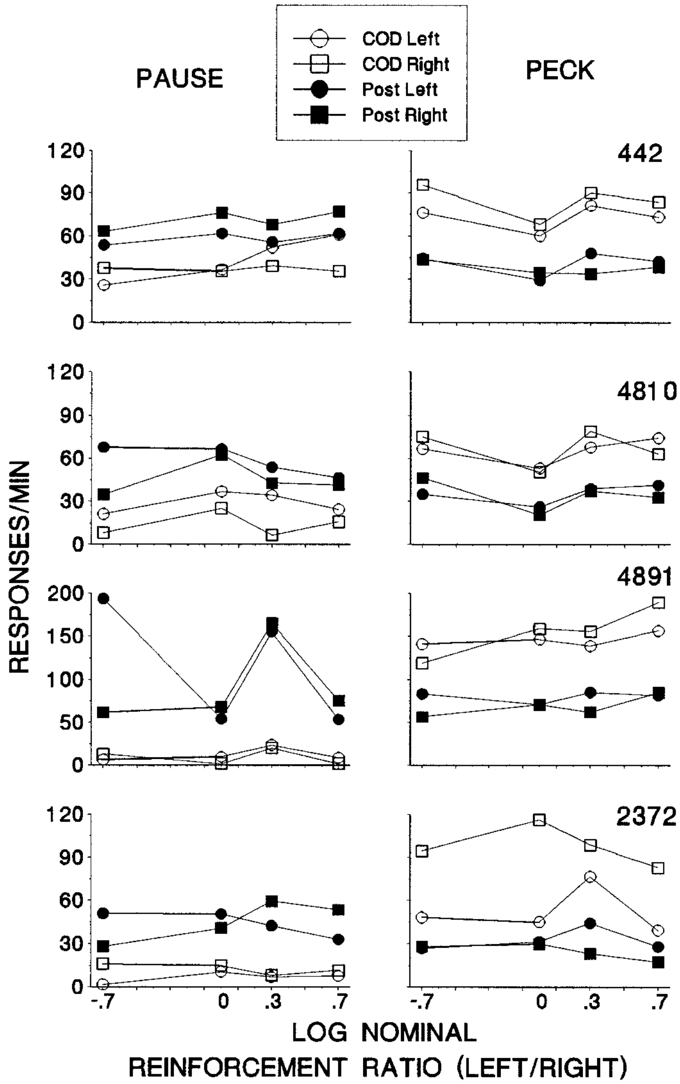

Fig. 6. Responses per minute during and following the COD for left and right keys in the pause-peck (left panels) and peck-peck (right panels) CODs as a function of log nominal reinforcement ratios for the left key. Open symbols represent COD responding, and closed symbols represent post-COD responding. COD rates were calculated by dividing COD responses by time spent in the COD. Post-COD rates were calculated by dividing total post-COD responses by total time spent after the COD. Data points represent the mean from the last five sessions of each condition.

peck-peck CODs than with pause-peck CODs. No consistent relation between any of the intervals and changes in reinforcement ratios was seen for pause-peck or peck-peck CODs.

Discussion

Pause-peck and peck-peck CODs produced similar matching relations in terms of total response distributions. For the peck-peck COD, severe undermatching was likely when only COD responses were considered (see also Silberberg & Fantino, 1970; Temple et al., 1995). Usually, the pause-peck COD produced less severe undermatching during the COD. The overmatching often obtained when only post-COD responding is considered (e.g., Temple et al., 1995) was not as extreme in the present experiment. However, in every case but one (Pigeon 4891, pause-peck COD), the sensitivity parameter of Equation 1 was higher for post-COD responses than for total responses.

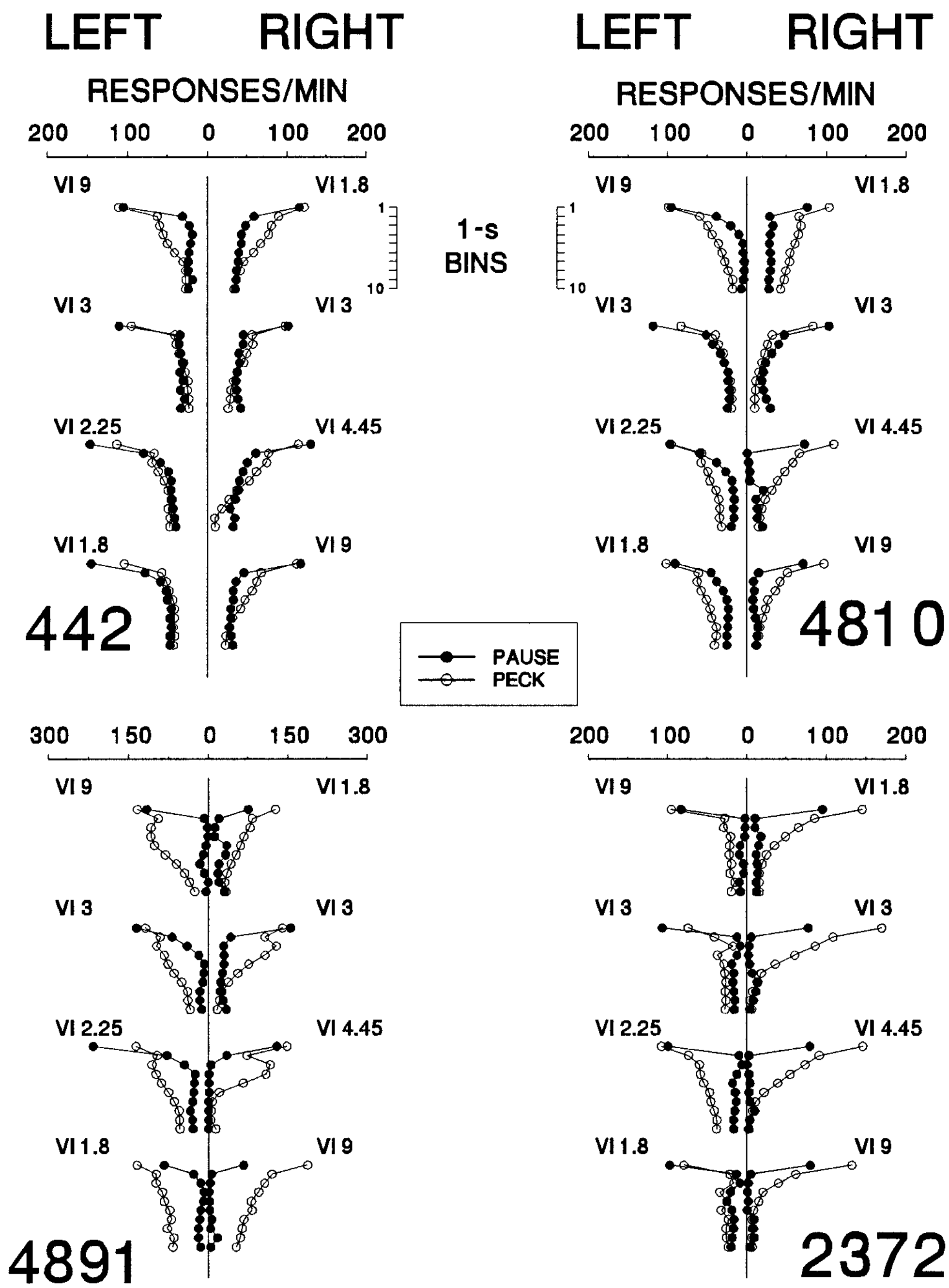

Fig. 7. Response rates in 1-s bins for the first 10 s following a changeover for pause-peck and peck-peck CODs. Response rates are presented for left and right keys for each relative reinforcement-rate condition. Data points represent the mean from the last five sessions of each condition.

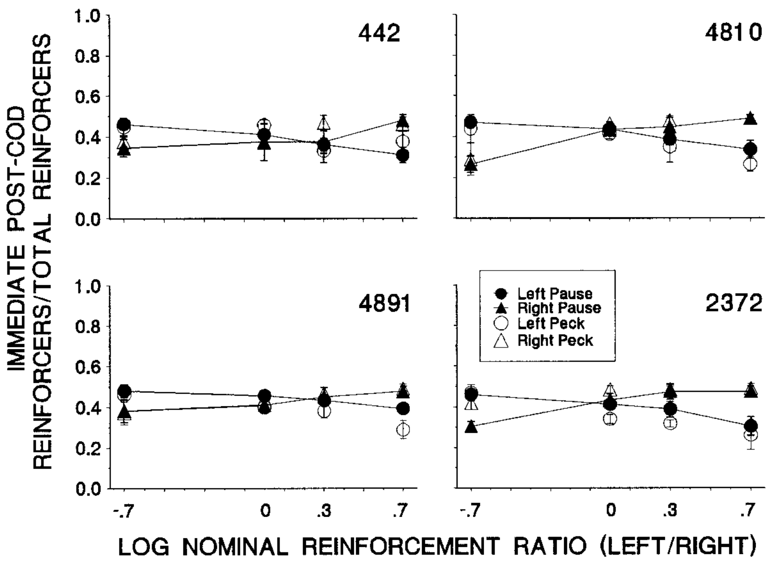

Fig. 8. Proportion of reinforcers delivered as a result of the first response on a alternative following termination of a COD, shown as a function of log nominal reinforcement ratios for the left key. Filled symbols represent the pause-peck COD, and open symbols represent the peck-peck COD. Left and right keys are represented by circles and triangles, respectively. Data points represent the mean of the final five sessions of each condition. Error bars represent ±1 *SD*.

Pause-peck and peck-peck CODs also resulted in differences in COD response rates. Consistent with previous data, the peck-peck COD produced high rates of COD responding and lower rates of post-COD responding (Pliskoff, 1971; Silberberg & Fantino, 1970). The opposite effect was produced by the pause-peck COD. In spite of these differences and differences in the matching relations describing COD and post-COD responding separately, both CODs yielded similar matching relations when COD and post-COD responses were combined.

It could be argued that the differences obtained between COD and post-COD response rates for the two types of COD reflect only differences in the way the CODs are defined rather than differences in the response patterns actually produced. The pause-peck COD includes travel time between the keys, whereas the peck-peck COD does not. The absence of responding during travel could artificially decrease COD response rates for the pause-peck COD. However, the patterns of responding for pause-peck and peck-peck CODs in the first 10 s following a changeover response (as shown in Figure 7) suggest differences in molecular response patterns. These patterns were obtained even when the disproportionate influence of travel time on the pause-peck COD response rates was excluded.

Response-rate differences produced by the two CODs in the first 10 s following a changeover may reflect differences in the B → S^R intervals obtained with the two CODs. After a changeover, response rates decreased more rapidly with the pause-peck COD than with the peck-peck COD. The B → S^R intervals obtained with the peck-peck COD were considerably longer than those obtained with the pause-peck COD. Alternatively, the differences in postchangeover response rates also may reflect differences in the total obtained CODs produced by the two types of COD. However, it seems unlikely that the longer total obtained COD produced by the peck-peck COD would result in higher postchangeover response rates. Regardless of the relevant interval in producing local response-rate differences, either interval would suggest the importance of the placement of the first reinforcer on the changed-to schedule in the production of postchangeover response rates (cf. Shull, Spear, & Bryson, 1981).

The finding that changeover rates differed as a function of COD type is consistent with and extends the results of Experiment 1.

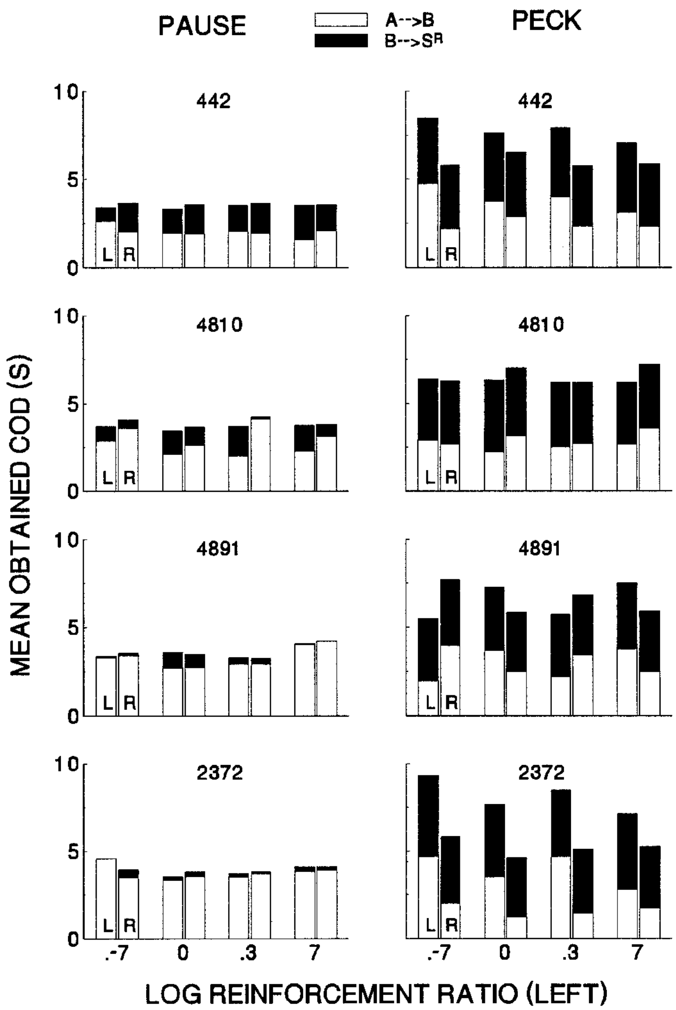

Fig. 9. Mean obtained CODs for pause-peck and peck-peck CODs in each log nominal reinforcement-ratio condition. Open portions of bars represent the interval from a response on Schedule A to a response on Schedule B (shown as A → B). Filled portions of bars represent the interval from a response on Schedule B to a reinforcer on Schedule B (shown as B → S^R). Open plus filled portions represent total obtained COD (the interval from a response on Schedule A to a reinforcer on Schedule B). Data represent means of the last five sessions of each condition, and L and R refer to changeovers to the left and right keys.

Changeover rates did not vary systematically as a function of the ratio of reinforcement rates on the two schedules when the data from individual subjects were considered. Others (e.g., Alsop & Elliffe, 1988; Herrnstein, 1961; Stubbs & Pliskoff, 1969) have reported that changeover rates are higher when equal concurrent VIs are scheduled and decrease as reinforcement ratios become more extreme. However, this effect is sometimes inconsistent when individual-subject data are considered. For example, Alsop and Elliffe presented data averaged across 6 subjects demonstrating that changeover rate varied with relative reinforcement rate. Examination of data in their appendix from individual subjects in the conditions with one and two reinforcers per minute (the reinforcement rates most similar to those in the present experiment) revealed that only 5 of 10 subjects showed the highest rates of changing over when the concurrent VIs were equal. In addition, only 4 of 10 subjects showed the highest rates of changing over when the VIs were equal and the lowest rates of changing over when the relative reinforcement rates were most extreme (this is true for 2 of 3 subjects in Stubbs & Pliskoff). The mean data from both types of COD in the present experiment approximate the mean data from Alsop and Elliffe's study; however, the concavity of the functions is less pronounced in the present data. The less pronounced concavity of the mean functions in the present experiment probably results from differences in the extremity of the reinforcement ratios that were investigated. Alsop and Elliffe examined reinforcement ratios as extreme as 8:1 (9:1 in Stubbs & Pliskoff), whereas the most extreme ratio in the present experiment was 5:1.

The differences in changeover rates and the similarity of the matching relations produced by pause-peck and peck-peck CODs are not surprising, given the data on obtained COD duration. The differences in rates of changing over produced by either type of COD were within the range of those that produce matching (Temple et al., 1995) and were similar to those produced by parametrically similar manipulations of peck-peck COD durations (Pliskoff, 1971; Shull & Pliskoff, 1967; Temple et al., 1995). Given that both types of COD produced similar matching relations and that in many cases the pause-peck COD produced $B \rightarrow S^R$ intervals of nearly zero, the total obtained COD appears to be the most important interval in determining the rate of changing between the alternatives. A direct comparison of pause-peck and peck-peck CODs, equal in terms of obtained COD, would allow an assessment of the importance of the obtained COD in determining changeover rates and response rates during and after the COD.

EXPERIMENT 3

Are the differences in total obtained COD between peck-peck and pause-peck CODs responsible for differences in rates of changing over and response rates during and after the COD? In this experiment, mean total obtained CODs ($A \rightarrow B + B \rightarrow S^R$ intervals) from a peck-peck COD obtained in Experiment 2 were programmed as pause-peck CODs in a within-subject yoked control design to answer this question.

Method

Subjects and Apparatus

Pigeons 442, 4810, and 2372 from Experiment 2 were used. The apparatus was the same as that used in Experiment 2.

Procedure

Concurrent VI 2.25-min VI 4.5-min schedules were used to allow comparisons with the data from Experiment 2. Mean total peck-peck CODs obtained from the last five sessions at the concurrent VI 2.25-min 4.5-min condition in Experiment 2 were programmed as pause-peck CODs in this experiment. For example, if the mean obtained peck-peck COD from Experiment 2 was 10 s, a pause-peck COD of 10 s was programmed. Changeover delays for each subject were as follows: Pigeon 442 (7.96 s and 5.78 s), Pigeon 4810 (6.20 s and 6.19 s), and Pigeon 2372 (8.48 s and 5.09 s) for changeovers to the left and right keys, respectively. These conditions were in effect until performance was stable, as defined in Experiment 2. Other details of the experiment were as described in Experiment 2.

Results

Figure 10 shows that obtained CODs for yoked pause-peck CODs did not differ systematically from the obtained peck-peck CODs from which they had been yoked. Pause-peck and peck-peck COD data from the log nominal reinforcement-ratio .3 condition (shown in Figure 9) are presented for comparison. Mean $A \rightarrow B$ and $B \rightarrow S^R$ intervals, as well as total mean obtained CODs, were similar for peck-peck and yoked pause-peck CODs. Figure 11 shows that changeover rates were more similar for yoked pause-peck and peck-peck CODs than for pause-peck and yoked pause-peck CODs (pause-peck and peck-peck data also appear in Figure 5).

Figure 12 shows log obtained reinforcement ratios minus log response ratios for pause-peck, peck-peck, and yoked pause-peck CODs for total, COD, and post-COD responding. Values greater than zero represent log response ratios that are smaller than log reinforcement ratios, and values less than zero represent log response ratios that are greater than log reinforcement ratios. The difference between log obtained reinforcement ratios and log obtained response ratios did not vary

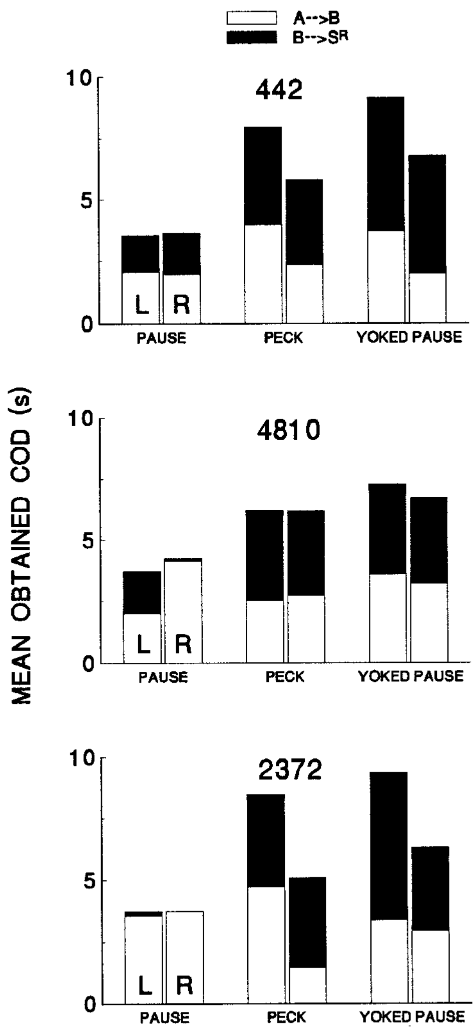

Fig. 10. Mean obtained CODs for pause-peck, peck-peck, and yoked pause-peck CODs at .3 log nominal reinforcement ratio. Data for pause-peck and peck-peck CODs are from Experiment 2. Data are presented as in Figure 9.

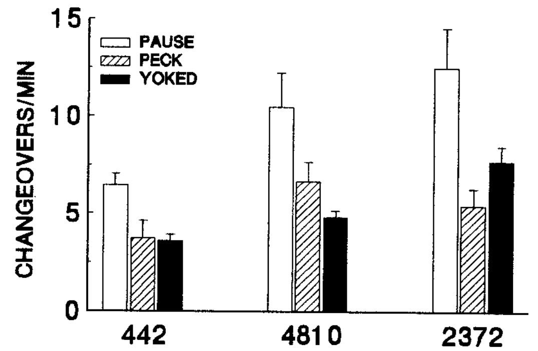

Fig. 11. Changeovers per minute for each subject in pause-peck, peck-peck, and no-COD conditions at .3 log nominal reinforcement ratio. Data for pause-peck and peck-peck CODs are from Experiment 2. Error bars represent +1 *SD*.

systematically for the three types of COD when total, COD, or post-COD responding is considered. These data suggest that the yoked pause-peck COD would not produce differences in matching from the pause-peck or peck-peck CODs if a range of relative reinforcement rates was examined (data for pause-peck and peck-peck CODs also appear in Figure 4). The data used to calculate ratios are available in the Appendix.

Figure 13 shows that the yoked pause-peck CODs yielded lower COD response rates than those produced by the equivalent-duration peck-peck CODs in Experiment 2. Post-COD response rates were relatively constant across all COD types (data for pause-peck and peck-peck CODs also appear in Figure 7). Response rates in each of the first 10 s after a changeover for pause-peck, peck-peck, and yoked pause-peck CODs are shown in Figure 14. For Pigeons 4810 and 2372, response rates across the first 10 s after a changeover were higher with the yoked pause-peck COD than with the pause-peck COD. For Pigeon 2372, response rates were the highest in the intervals near those that corresponded to the end of the B $\rightarrow$ S^R interval (shown in Figure 10). Response rates of Pigeon 442, for which pause-peck and peck-peck local response rates did not differ in the .3 log reinforcement ratio condition, were similar for all three CODs on the right key, but were lower on the left key when the yoked pause-peck COD was in effect.

Discussion

The correspondence between obtained response and reinforcement ratios did not differ systematically for yoked pause-peck, pause-peck, and peck-peck CODs. The similar relations between response and reinforcement ratios that were obtained with peck-peck CODs and pause-peck CODs of equal durations support the conclusion from Experiment 2 that the two CODs produce similar matching relations.

Post-COD response rates were relatively constant across all of the types of COD studied, but COD response rates varied. Response rates

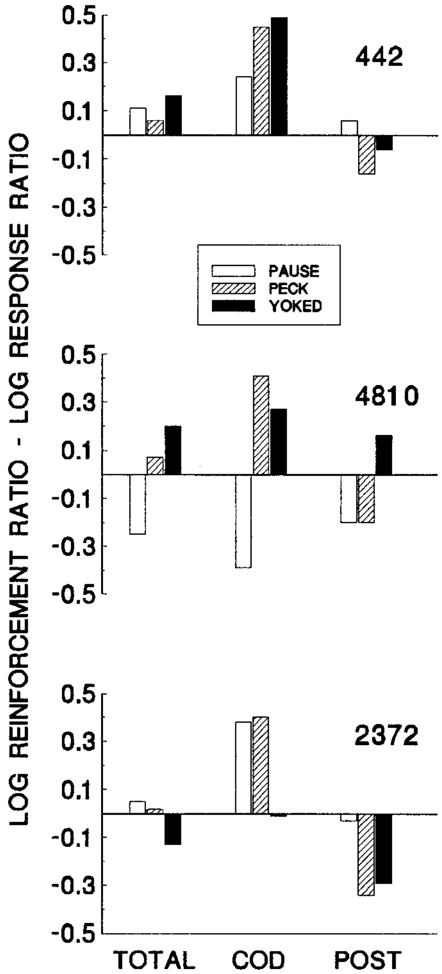

Fig. 12. Log obtained reinforcement ratios minus log response ratios obtained at .3 log nominal reinforcement ratio for total, COD, and post-COD responses. Mean data are presented for the last five sessions of each condition for pause-peck (from Experiment 2), peck-peck (from Experiment 2), and yoked pause-peck CODs. Raw data are available in the Appendix.

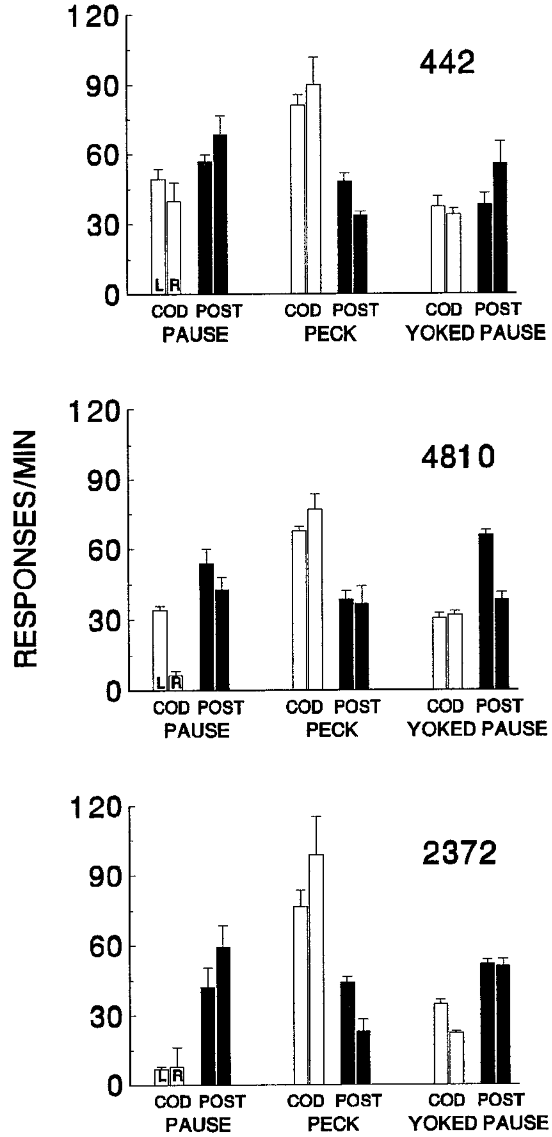

Fig. 13. Response rates during and after the COD for pause-peck, peck-peck, and yoked pause-peck CODs. Data for pause-peck and peck-peck CODs are from Experiment 2. Error bars represent +1 *SD*.

during the yoked pause-peck COD were lower than those obtained with the peck-peck COD. When a pause-peck COD of sufficient length was used (5 to 10 s in the current experiment), response rates during and after the COD were more similar than those produced with the peck-peck COD. In addition, when the yoked pause-peck COD was in effect, response rates increased in the 10 s following a changeover for the 2 pigeons that showed lower response rates in similar intervals when a pause-peck COD was in effect in Experiment 2. The persistence of higher response rates after a changeover obtained with the yoked pause-peck COD probably resulted from the longer $B \rightarrow S^R$ intervals obtained with the yoked pause-peck COD. These data and those from Experiment 2 suggest that the $B \rightarrow S^R$ interval may be instrumental in determining response rates after a changeover. However, changes in the $B \rightarrow S^R$ interval occurred only when total obtained COD was varied; therefore, either interval could be responsible for

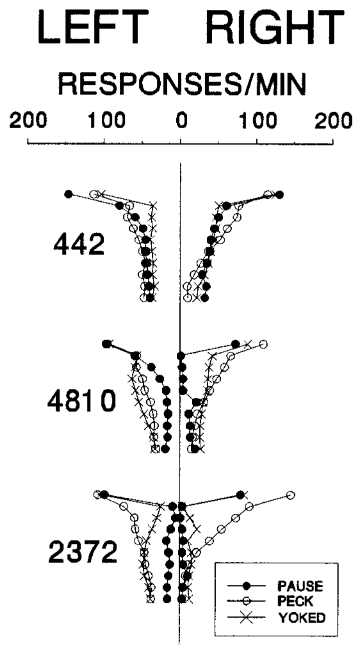

Fig. 14. Response rates in 1-s bins for the first 10 s following a changeover for pause-peck, peck-peck, and yoked pause-peck CODs. Data are as presented in Figure 7; data for pause-peck and peck-peck CODs are from Experiment 2.

the production of postchangeover response rates.

Similar rates of changing over for pause-peck and peck-peck CODs occurred when the obtained COD durations were equated. This finding implies that the differences in changeover rates produced by pause-peck and peck-peck CODs in Experiments 1 and 2 may have resulted from total obtained COD duration differences. Interpretation of the role of total obtained COD duration is complicated, however, because the changes in total obtained COD durations that resulted from yoking were confounded with changes in the B $\rightarrow$ S^R interval.

Although changes in the B $\rightarrow$ S^R interval could be responsible for changes in the rates of changing over, the role of the B $\rightarrow$ S^R interval in producing matching is unclear. Matching was obtained with a pause-peck COD in Experiment 2 when this interval was often near zero. It might be argued that because matching was obtained with both types of COD and the A $\rightarrow$ B interval remained relatively constant across CODs, the A $\rightarrow$ B interval is the most important for the production of matching. This account is consistent with Baum's (1982) observations of the effects of travel on changing over and its relation to matching. However, it seems unlikely that the A $\rightarrow$ B interval is of primary importance in terms of the function of the COD given that this interval is present when no COD is programmed and that under these conditions matching typically is not obtained. When the travel time between the alternatives is long enough (e.g., Baum, 1982), it may be functionally equivalent to the total obtained COD in that responses on one alternative are separated temporally from reinforcers on the other.

GENERAL DISCUSSION

Functions posited for the COD in concurrent schedules include the temporal separation of the component schedules and the mediation of matching via the determination of local response rates. The present results suggest that, although both effects may contribute, the COD operates to separate the component schedules temporally, but its type does not affect the overall distribution of responses among the alternatives (matching).

Despite the fact that peck-peck and pause-peck CODs yielded different local response rates during and after the COD, similar matching relations were observed. This finding is counter to earlier suggestions that matching results from high rates of responding during the COD produced by the peck-peck COD (cf. Iversen, 1991; Silberberg & Fantino, 1970; Temple et al., 1995). The occurrence of matching and the use of a peck-peck COD have overlapped in previous experiments, which sometimes led to the conclusion that the patterns of responding (i.e., the local response rates during and after the COD and the local matching relations that result from them) generated by peck-peck CODs were a necessary component of matching. The present data show that no one pattern of responding during and after the COD is necessary for matching.

Even though different COD arrangements do not affect molar matching, they do affect not only local response rates, as noted above, but also changeover rates. The importance of changeover rates in matching has been noted in previous discussions of the function of the

COD (e.g., Baum, 1979; Catania, 1966; Catania & Cutts, 1963; Herrnstein, 1961). In particular, the inverse relation between COD duration and changeover rate (Pliskoff, 1971; Shull & Pliskoff, 1967; Temple et al., 1995) has been exploited as a way of investigating the effects of the degree of temporal separation of the component schedules. Historically, such relations have been established by the use of peck-peck CODs.

The use of COD procedures, whether peck-peck, pause-peck, or CODs arranged in relation to explicit changeover responses using changeover-key procedures (e.g., Pliskoff, 1971), confound the effects of the total obtained COD (the last response on A to the next reinforcer on B) and $B \rightarrow S^R$ intervals in achieving the temporal separation of the two components. Claims of the importance of the COD duration, and thus temporal separation of responses on A from reinforcers on B, in producing matching typically do not take into account the independent contributions of these different temporal intervals. Thus, either the programmed interval arranged by a COD measured from the first response on B (the changeover response) to the next reinforcer for a B response or the total changeover time, which includes not only the $B \rightarrow S^R$ interval but also the time from the last response on A to the next response on B, or both, could be implicated in COD duration effects. Separating these two intervals is difficult, as suggested by the results of the present Experiment 3, in which yoking the total obtained COD duration from peck-peck to pause-peck CODs also produced changes in the $B \rightarrow S^R$ interval.

The importance of separating the effects of the total obtained COD and the $B \rightarrow S^R$ interval results because the two intervals may have different implications for an understanding of matching. If the total obtained COD is the major determinant of changeover rates, then the COD can be seen as functionally separating the alternatives by breaking up patterns of responding across the alternatives and ''allowing choice between them to occur'' (Baum, 1979, p. 279). That is, the COD merely prevents adventitious sequences of responding across the alternatives and allows control of behavior by the relative reinforcement rates that are arranged by the two functionally independent schedules. From this perspective, changeover behavior would be a by-product of control by relative reinforcement rates except when the COD is absent and strict alternation of responding between the component schedules occurs. Alternatively, if the $B \rightarrow S^R$ interval is primary, then the COD may have its effects on matching by arranging the first delay to reinforcement after a changeover response (cf. Pliskoff, 1971; Shull et al., 1981). If the delay from a changeover response to reinforcement is the critical feature of the COD, then further credence accrues to theoretical accounts of matching based on its mediation by changeover behavior (e.g., Myerson & Miezin, 1980; Vaughan, 1982; see also Williams & Bell, 1996).

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APPENDIX

				Time (min)				Responses					
		VI (min)		Left		Right		Left		Right		Reinforcers	
Pigeon	COD in effect	Left	Right	COD	Post	COD	Post	COD	Post	COD	Post	Left	Right
442	Pause	3	3	13.6	16.4	14.6	18.8	551.8	949.2	559.6	1,239.0	20.0	20.0
		1.8	9	16.0	57.8	16.2	10.4	973.4	3,561.6	578.8	792.0	30.8	9.2
		2.25	4.45	8.9	30.2	9.6	13.3	462.4	1,682.5	376.6	896.2	27.0	13.0
		9	1.8	19.7	16.1	21.6	39.7	508.8	870.8	811.2	2,504.4	10.0	30.0
442	Peck	3	3	7.3	20.9	7.7	30.0	438.4	621.4	524.2	1,035.8	19.0	21.0
		1.8	9	8.9	47.1	9.1	23.3	651.0	2,036.6	759.0	893.0	32.2	10.8
		2.25	4.45	6.7	40.8	6.8	16.0	541.2	1,947.2	606.6	537.8	28.8	11.4
		9	1.8	11.7	24.8	12.2	58.7	891.8	1,099.4	1,161.6	2,564.2	9.4	30.6
442	Yoked	2.25	4.45	13.2	32.3	10.3	7.1	415.6	1,193.2	465.0	377.0	29.0	11.0
4810	Pause	3	3	15.8	15.9	15.7	15.8	586.2	1,020.2	401.0	966.0	20.4	19.6
		1.8	9	21.1	41.9	20.0	10.0	527.2	1,906.4	319.4	411.2	31.8	8.2
		2.25	4.45	16.9	23.1	16.3	8.0	547.0	1,203.6	104.6	338.2	27.2	12.8
		9	1.8	14.8	7.6	14.4	61.2	320.4	505.0	121.8	2,112.2	8.8	31.2
4810	Peck	3	3	10.4	31.6	10.1	15.5	543.4	828.6	506.6	319.2	20.6	19.4
		1.8	9	8.4	68.9	8.1	10.6	630.8	2,836.6	508.6	649.8	30.2	9.8
		2.25	4.45	8.3	37.7	8.3	12.7	559.4	1,452.6	656.0	477.4	27.2	12.8
		9	1.8	8.7	14.0	9.8	59.6	582.8	512.6	745.6	2,714.0	9.4	30.6
4810	Yoked	2.25	4.45	16.5	15.5	13.8	17.9	502.6	1,023.0	442.2	687.4	27.0	13.0
4891	Pause	1.8	9	24.9	34.6	25.0	11.6	224.0	1,866.4	37.8	826.8	30.8	9.2
		3	3	16.0	9.9	15.7	21.4	583.4	1,335.8	426.6	2,006.2	20.6	19.4
		9	1.8	25.4	6.7	25.4	35.2	156.2	1,299.4	333.4	2,073.0	9.2	30.8
		2.25	4.45	17.9	19.4	18.4	6.0	417.6	3,001.4	362.0	976.2	25.4	14.6
4891	Peck	1.8	9	6.5	65.9	6.7	15.1	1,023.8	5,364.8	1,269.8	1,289.6	32.0	8.0
		3	3	8.4	29.3	8.7	17.7	1,234.8	2,082.4	1,388.6	1,252.6	20.4	19.6
		9	1.8	11.3	27.0	10.5	44.4	1,618.8	2,211.6	1,232.2	2,541.2	12.8	27.2
		2.25	4.45	8.3	35.5	7.2	11.0	1,150.8	3,038.8	1,114.8	682.2	26.2	13.8
2372	Pause	1.8	9	19.7	43.4	19.6	7.2	149.6	1,420.6	223.2	383.6	32.2	7.8
		3	3	18.9	17.4	19.3	8.6	199.4	860.0	291.4	343.2	21.4	18.6
		9	1.8	20.1	12.8	20.6	43.7	32.2	589.6	331.2	1,220.6	10.4	29.6
		2.25	4.45	18.2	21.9	18.3	6.9	127.4	885.4	148.8	403.0	27.4	12.6
2372	Peck	1.8	9	9.7	74.3	8.7	7.8	380.6	2,072.0	719.0	146.2	30.0	10.0
		3	3	10.0	33.0	9.8	14.3	447.8	1,035.0	1,137.8	425.0	20.4	19.6
		9	1.8	15.7	18.3	17.9	48.7	755.8	493.8	1,704.6	1,355.0	9.6	30.4
		2.25	4.45	8.3	35.7	7.8	15.4	630.4	1,490.2	777.2	357.6	26.8	13.2
2372	Yoked	2.25	4.45	25.6	18.8	17.5	4.4	886.2	967.2	389.8	221.8	27.6	12.4

Note. Data are means of the last five sessions of each condition.